Farm and Non-Farm Labor Decisions and Household Efficiency

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Abstract

This paper develops a theoretical framework for modeling farm households' joint production and consumption decisions in the presence of technical inefficiency. Following Lopez (1984), a household model where farmers display different preferences between on-farm and off-farm labor is adopted while their production activity can be subject to technical inefficiency. The presence of technical inefficiency does not only lead to the inability of farmers to achieve maximal output but it will also affect the consumption allocation and the household's labor supply decisions through its effect on both income and on the shadow price of on-farm labor, leading to overall household inefficiency. An application to a panel dataset of 296 farms in the UK illustrates the basic concepts introduced in the theoretical model. The results show that households in our sample are technically inefficient but their efficiency scores are very close. However there is a big dispersion in the household efficiency scores and some households can adapt better their consumption and labor supply decisions when production is technically inefficient.

Keywords: non-separable agricultural household model; household and farm efficiency; cereal farms; UK

JEL Codes: *C41*, *O16*, *O33*, *Q25*.

Introduction

Based on the seminal works of Debreu (1951) and Farrell (1957), much research has been devoted the last decades to the investigation of technical inefficiency of farming households in both developed and developing countries. The majority of this empirical work has been focused almost exclusively on the performance evaluation of farm activities, that is, on farmers' ability to utilize efficiently existing crop or livestock technology.[1] Moving away from the traditional microeconomic paradigm, this vast literature provided a more realistic framework of farmer's behavior allowing them to make mistakes in the production of farm output and resource use. Yet, production and consumption decisions within rural households are linked as the deciding entity is both a producer, choosing the allocation of labor and other inputs to farm production, and a consumer, choosing the allocation of income from farm profits and labor sales to the consumption of commodities and services.[2] Hence, if production and consumption decisions are not independent, the way that farm resources are utilized in crop or livestock production is directly affecting individual decisions and the overall efficiency of farming households.

Building upon the classic works by Singh, Squire and Strauss (1986) and others, a series of agricultural household models have been developed aimed to analyze consumption decisions by rural households.[3] Among those, the nonseparable household modeling apparatus has become the workhorse for the analysis of labor supply decisions. With perfectly competitive markets for all inputs and all outputs, price-taking farming households would make separate decisions regarding production and consumption. First, household is choosing inputs and outputs to maximize profits in all farming activities given its production possibilities and then allocate its full income to the consumption of goods, services and leisure maximizing welfare for family members. Ownership of the variable factors of production and labor supplied on-farm is irrelevant for farming decisions and affect consumption only through income level including profits generated by farm activities. In these instance measuring efficiency of farm production independently from household decisions is legitimate assuming though that household members are aware of their mistakes in utilizing farm technology appropriately in maximizing their own utility.

Typically, some type of markets for factors of production or crops produced may exist even in the underground economy. However, still markets may fail for farming households when they face wide margins between selling and buying prices for any factor of production (including family labor)

[1]Solis *et al.*, (2007), in their meta-regression analysis, provide an excellent review of 167 relevant studies in developed and developing countries.

[2]According to Sadoulet and de Janvry (1995) the key element in defining the household is identifying the decision making unit which sets the strategy concerning the generation of income and the use of this income for consumption and reproduction.

[3]Taylor and Adelman (2003) provide an excellent synthesis of agricultural household modeling, its evolution and empirical uses in both developed and developing countries.

or farm output produced (de Janvry *et al.*, 1991; Key *et al.*, 2000).[4] According to Sadoulet and de Janvry, (1995) these price margins are affected by: *a.* differences in transactions costs, e.g., distance from the market, poor public infrastructure, monopoly power by local wholesalers, information asymmetries and incentive costs on hired labor; *b.* shallow markets vulnerable to variation in crop production locally; *c.* farmers' risk aversion as selling or buying prices are discounted by household members to hedge against risk; and *d.* by limited access to working capital credit as households need to balance their budget throughout cropping season. An additional reason that contributes to rural markets failure, widening further crop price margins for households, is the existence of technical inefficiency in farm production. In effect, failure to utilize farm technology efficiently, implies that revenues generated from crop or livestock production are less than those associated with maximal output reducing effective crop price for household members. Farm profits are lower than those expected and households are forced to diversify labor and land resources as a precaution altering their optimal consumption decisions.

Family labor is a quasi-fixed input for rural households and it's allocation between farm and non-farm activities has important consequences on their welfare. Market inconsistencies and household's inability to utilize optimally farm technology are affecting optimal behavior resulting in turn to further inefficiencies at the household level. Equilibrium wage rates and employment levels in rural areas depend not only on the demand for labor, but also on households' labor supply decisions. Thus, the effectiveness of policy or project interventions to assist rural households depends crucially on labor supply behavior taking into account at the same time efficiency in farm production. Therefore measuring the extent to which household members are making allocation errors as a response to farming inefficiencies is important element of efficiency analysis particularly for small family farms that hinge on off-farm income to sustain their farming activities and their prosperity.

Nevertheless, a significant part of the empirical research on farm efficiency in both developed and developing countries is using off-farm income levels to explain technical efficiency differentials among rural households as a driving force for improved (or deteriorated in some instances) resource utilization in farm production (*e.g.*, Pfeifer *et al.*, (2009), Lien *et al.*, (2010), Chang and Wen (2011). Besides erroneously assuming a separable agricultural household model structure, this part of the agricultural economics literature ignores the interdependence between farm production and consumption inherent in households' decision making process. To our knowledge there are only three papers dealing appropriately with the interdependence between production and consumption sides of farm households in an attempt to measure overall household inefficiency. Chavas *et al.*, (2005) first argued that under labor market rigidities the appropriate level of analysis is the rural

[4] In a statistical context, Le (2010) using Benjamin's (1992) and Jacoby (1993) tests rejected the separation model hypothesis in a sample of Vietnamese rural households under different model specifications and estimation methods validating the non-separation assumption for family farms.

household. He assumes though a joint technology of farm and non-farm activities utilizing a profit frontier to estimate non-parametrically technical, allocative and scale efficiency at the household level. Along this line Fletschner (2008) and Lovo (2011) provided empirical measures of household inefficiency for a sample of rural farmers in Paraguay and South Africa, respectively. All three papers are treating off-farm income as a separate output of farming household technology that is fitted into the conventional warehouse of non-parametric or stochastic frontier analysis to measure all types of inefficiencies at a household level.

Along the same line, the present paper develops a rural household model, based on Lopez (1984) non-separable assumption of household decisions and using Kumbhakar (2001) and Chambers *et al.*, (2010) definitions of profit efficiency, tracing the impact that farm inefficiencies may have on individual consumption decisions. Allowing errors in the utilization of farm technology, ensures that maximal potential farm output is not attained. Rational rural households, realizing that on-farm family labor is less profitable, responds by altering labor supply decisions between on- and off-farm activities. Leisure and marketed good consumption is reduced due to lower farm profits, but at the same time households switch family labor resources to off-farm activities to mitigate losses in their welfare. Therefore, instead of assuming a joint household technology, we provide a theoretical framework to disentangle these effects and measure the actual losses of household members from failing to utilize efficiently farming technology.

The rest of the paper is structured as follows. Next section develops develops a non-separable agricultural household model under farm technical inefficiency. This is followed by the description of the survey data and the empirical model adopted to approximate farm technology and household preferences including the econometric model used in the estimation. The next section presents and discusses the estimation results and finally, the last section concludes the paper.

A Non-Separable Household Model Under Technical Inefficiency

Production Decisions

The crop production technology in period t for a rural household with specific characteristics $s \in \Re_+^K$, is represented by the closed, non-empty production possibilities set

$$T(s,t) = \left\{ \left(x^v, x^f, y \right) : \left(x^v, x^f \right) \text{ can produce } y \text{ for a given level of } (s,t) \right\}$$

where $x^v \in \Re_+^N$ is a vector of variable inputs, $x^f \in \Re_+$ is family labor used in crop production which is considered to be the only quasi-fixed input, and y is crop output. Assuming farmers being technically inefficient, then farm technology may be defined as

$$T(s,t) = \left\{ \left(x^v, x^f, y \right) : \ y \leq f\left(x^v, x^f, t \right) \theta^p, \ \theta^p = g\left(s,t\right) \right\} \tag{1}$$

where $f\left(x^v, x^f, t\right)$ represents maximal crop output obtained from variable input and family labor use, and $\theta^p = g\left(s,t\right)$ whose range is restricted to lie in $[0,1]$, represents the percentage of maximal output realized by farm households in the presence of technical inefficiency in crop production. Following Kumbhakar *et al.*, (1991) we assume that it is affected by household characteristics and it changes over time as household adjust themselves to better farming practices. Further, we assume that long-run maximal crop output technology exhibits constant returns-to-scale in both variable inputs and family labor employment. That is, it holds

$$f\left(\lambda x^v, \lambda x^f, t\right) = \lambda f\left(x^v, x^f, t\right) \quad \forall \lambda > 0$$

Since family labor is the only quasi-fixed inputs utilized by household members in crop production, then we may define a restricted profit function which measures the quasi-rents that a rural household collects from its quasi-fixed input endowment *i.e.*, on-farm labor supply by household members. For a household facing crop price $p^y \in \Re_{++}$ and variable input prices $w^v \in \Re^J_{++}$, the maximal quasi-rent from farming with a a family labor input endowment of x^f is that obtained in the absence of technical inefficiency in crop production *i.e.*, when $\theta^p = 1$:

$$\begin{aligned} \pi\left(p^y, w^v, x^f, t\right) &= \max_{x^v, y} \left\{ p^y y - w^v x^v : \left(x^v, x^f, y\right) \in T(s,t) \right\} \\ &= \max_{x^v, y} \left\{ p^y y - w^v x^v : \ y \leq f\left(x^v, x^f, t\right) \right\} \\ &= \max_{x^v} \left\{ p^y f\left(x^v, x^f, t\right) - w^v x^v \right\} \end{aligned}$$

where $\pi\left(p^y, w^v, x^f, t\right)$ is the restricted profit function defined in terms of on-farm labor employment by household members in the absence of technical inefficiency. The restricted profit function defined above is sublinear (positive linear homogeneous and convex) in output and variable input prices, non-decreasing in output price and non-increasing in variable input prices.

Given that long-run crop technology exhibits constant returns-to-scale, the profit function is also positive linear homogeneous in on-farm labor employment, *i.e.*, $\pi\left(p^y, w^v, \mu x^f, t\right) = \mu\pi\left(p^y, w^v, x^f, t\right)$ $\forall \mu > 0$. This implies that under a smooth farm production technology the returns of on-farm labor employment can be obtained from:

$$\pi\left(p^y, w^v, x^f, t\right) = x^f \pi^f\left(p^y, w^v, t\right) \tag{2}$$

In other words, $\pi^f(p^y, w^v, t)$ is the on-farm wage rate (*i.e.*, the shadow price of on-farm labor) which is also sublinear in output and variable input prices, non-decreasing in output price and non-increasing in variable input prices.

The separable nature of the crop technology in (1) facilitates going from maximal possible quasi-rent to maximal quasi-rent realized in the presence of technical inefficiency in crop production. From the specification of $T(s,t)$ household's quasi-rent from farming obtained in the presence of technical inefficiency is (Kumbhakar, 2001; Chambers *et al.*, 2010):

$$\begin{aligned} \Pi\left(p^y, w^v, x^f, s, t\right) &= \max_{x^v, y}\left\{p^y y - w^v x^v : y \le f\left(x^v, x^f, t\right) g(s,t)\right\} \\ &= \max_{x^v}\left\{p^y g(s,t) f\left(x^v, x^f, t\right) - w^v x^v\right\} \\ &= \tilde{\pi}\left(p^y g(s,t), w^v, x^f, t\right) \\ &= x^f \tilde{\pi}^f\left(p^y g(s,t), w^v, t\right) \end{aligned} \tag{3}$$

Moving from the second to the third line of the above definition is necessary to recognize that when there is no technical inefficiency household revenues from farming are all revenues associated with maximal output, *i.e.*, $p^y f\left(x^v, x^f\right)$. However, when the utilization of variable inputs or on-farm household employment are not efficient then the household enjoy only $p^y f\left(x^v, x^f\right)\theta^p$ where $\theta^p \le 1$, so $p^y\theta^p \le p^y$. Thus, the presence of technical inefficiency in economic terms is exactly the reduction in the effective crop price for household members. The last line of the definition is obtained from relation (2) above.

If there is a unique quasi-rent maximizing input demands and supply, then through *Hotelling's Lemma* $\Pi\left(p^y, w^v, x^f, s, t\right)$ is differentiable in p^y and w^v providing

$$\begin{aligned} y\left(p^y, w^v, x^f, s, t\right) &= \Pi_p\left(p^y, w^v, x^f, s, t\right) \\ &= \tilde{\pi}_{\tilde{p}}\left(p^y g(s,t), w^v, x^f, t\right) g(s,t) \\ &= x^f \tilde{\pi}^f_{\tilde{p}}\left(p^y g(s,t), w^v, t\right) g(s,t) \end{aligned} \tag{4}$$

$$\begin{aligned} -x^v\left(p^y, w^v, x^f, s, t\right) &= \Pi_w\left(p^y, w^v, x^f, s, t\right) \\ &= \tilde{\pi}_w\left(p^y g(s,t), w^v, x^f, t\right) \\ &= x^f \tilde{\pi}^f_w\left(p^y g(s,t), w^v, t\right) \end{aligned} \tag{5}$$

where $\Pi_p \in \Re_+$ denotes the partial derivative of Π in p^y, $\tilde{\pi}_{\tilde{p}} \in \Re_+$ the partial derivative of $\tilde{\pi}$ with respect to it's first argument $p^y g(\cdot)$, and Π_w or $\tilde{\pi}_w \in \Re^J_-$ denotes the gradient of Π and $\tilde{\pi}$ in w^v.

The quasi-rent loss for household members associated with the presence of technical inefficiency in crop production is the difference between maximal possible quasi-rent and quasi-rent realized in the presence of technical inefficiency:[5]

$$\Theta^{\pi}\left(p^{y},w^{v},s,t\right)=x^{f}\left(\pi^{f}\left(p^{y},w^{v},t\right)-\tilde{\pi}^{f}\left(p^{y}g\left(s,t\right),w^{v},t\right)\right)\geq 0$$

or in percentage terms of realized quasi-rents

$$\theta^{\pi}\left(p^{y},w^{v},s,t\right)=\frac{\tilde{\pi}^{f}\left(p^{y}g\left(s,t\right),w^{v},t\right)}{\pi^{f}\left(p^{y},w^{v},t\right)} \tag{6}$$

which is actually profit efficiency of rural households in the presence of technical inefficiency in crop production. Subtracting θ^{π} from θ^{p} (after dropping function arguments for $g\left(s,t\right)$):

$$\begin{aligned}\theta^{p}\left(s,t\right)-\theta^{\pi}\left(p^{y},w^{v},s,t\right) &= g-\frac{\tilde{\pi}^{f}\left(p^{y}g,w^{v},t\right)}{\pi^{f}\left(p^{y},w^{v}t\right)}\\ &= \frac{g\pi^{f}\left(p^{y},w^{v}t\right)-\tilde{\pi}^{f}\left(p^{y}g,w^{v},t\right)}{\pi^{f}\left(p^{y},w^{v},t\right)}\\ &= \frac{\pi^{f}\left(p^{y}g,w^{v}g,t\right)-\tilde{\pi}^{f}\left(p^{y}g,w^{v},t\right)}{\pi^{f}\left(p^{y},w^{v},t\right)}\geq 0\end{aligned} \tag{7}$$

The third equality follows from the positive linear homogeneity of restricted-profit functions in input and output prices. The final inequality follows because the restricted-profit function is non-increasing in input price and $g(s,t)\leq 1$. The economic explanation is straightforward. First, a technically inefficient farm operation ensures that maximal potential crop output is not attained. A rational rural household, realizing that variable-input use is now less profitable, responds by lowering his maximal potential output from $\pi_{p}\left(p^{y},w^{v},x^{f},t\right)$ to $\tilde{\pi}_{p}\left(p^{y}g\left(s,t\right),w^{v},x^{f},t\right)$. As we show before, household's rational response is isomorphic to his rational response to a decrease in the price of output. This in turn implies that maximal potential supply adjusts downward. On the other hand, this supply reduction evokes a cost saving, as rational households reduce their use of some variable inputs (including family labor) and rearrange the utilization of others. However, revenue losses due to supply reduction are greater than cost-savings associated with rational profit-maximizing producers conserving on variable cost as a consequence of their rational supply reduction.

Consumption Decisions and Labor Supply

On the consumption side, we assume that household members are endowed with $\bar{T}$ units of time which can be consumed as leisure,[6] supplied to the market as labor or used in farm operation. Following Lopez (1984), we further assume that members of farm household confront different

[5] We assume that households are not making allocative errors concerning crop and variable inputs prices in farm production. Our analysis can be extended in that direction making though the econometric estimation of the empirical model unnecessarily complicated.

[6] Leisure is assumed to be a normal good for household members.

disutilities from working on- and off-farm or in other words they supply heterogeneous farm and non-farm labor.[7] Finally, household and hired labor are not perfect substitutes in farm production due to supervision costs or differences in educational level and experience between farm operators and hired labor.[8]

Under these assumptions rural households have the following general utility function:

$$u = u\left(\ell^f, \ell^o, c\right)$$

where $\ell^f = \bar{T} - x^f$, $\ell^o = \bar{T} - x^o$ is the total leisure enjoyed by household members arising from different employment opportunities with $x^f \in \Re_+$ being the hours worked on-farm and $x^o \in \Re_+$ the hours worked in non-farm activities, and $c \in \Re_+$ is an aggregate marketed good consumed by household members. The utility function defined above is continuous, concave and, non-decreasing in aggregate marketed good and non-increasing in x^f and x^o.

Assuming that farm operation is perfectly efficient, the agricultural household income consists of profits obtained from farming activities, the non-labor exogenous income which includes the returns obtained from financial and real assets owned by household members and, the income obtained from off-farm employment, *i.e.*

$$p^c c = \pi\left(p^y, w^v, x^f, t\right) + w^o x^o + M_0$$

or using (2)

$$p^c c = \pi^f\left(p^y, w^v, t\right) x^f + w^o x^o + M_0$$

where $p^c \in \Re_{++}$ is the price of aggregated marketed good, $w^o \in \Re_{++}$ is the off-farm wage rate, and $M_0 \in \Re_+$ is the exogenous non-labor income.

Hence, agricultural household's utility maximization problem may be now stated as:

$$\max_{l^f, l^o, c} \left\{u\left(\ell^f, \ell^o, c\right) : M = p^c c + \pi^f\left(p^y, w^v, t\right) \ell^f + w^o \ell^o\right\} \tag{8}$$

where $M = \bar{T}\left(\pi^f\left(p^y, w^v, t\right) + w^o\right) + M_0$ is household total income obtained from farm production, off-farm employment and non-labor sources. Assuming that at all off-farm wage rates and commodity prices household members consume some leisure, the solution of the above maximization

[7] From a different perspective there are differences in the commuting cost between farm operation and wage employment.

[8] Sonoda (2008) developed a series of Cox-type tests rejecting the existence of the homogeneous agricultural labor supply model In Japan's agriculture. Lopez (1984) arrived at the same conclusions for Canadian agriculture using though a different statistical approach.

problem implies that the marginal rate of substitution between the two types of leisure is equal with their relative prices, *i.e.*,

$$\left(MRS_{f,o}=\right)\frac{\partial u/\partial \ell^o}{\partial u/\partial \ell^f}=\frac{w^o}{\pi^f\left(p^y,w^v,t\right)} \tag{9}$$

However, if household members fail to operate efficiently their farming activities, then they do not satisfy the above optimality condition changing also the allocation of their labor supply. It holds that

$$\frac{w^o}{\pi^f\left(p^y,w^v,t\right)}\leq\frac{w^o}{\tilde{\pi}^f\left(p^y g\left(s,t\right),w^v,t\right)}$$

since $\pi^f\left(p^y,w^v,t\right)\geq\tilde{\pi}^f\left(p^y g\left(s,t\right),w^v,x^f,t\right)$ the marginal utility of leisure ℓ^f is less than the optimal quasi-rents obtained from crop production due to technical inefficiency. This implies that household members decrease the supply of labor to crop production and increase off-farm labor supply until the optimality conditions in (9) is satisfied. At the same time income from farming is reduced due to the presence of technical inefficiency. This in turn implies that the supply of both types of labor is increased given that leisure is a normal good. Hence, under technical inefficiency off-farm labor supply always increases whereas the net effect on farm labor supply depends on the magnitude of income effect. This is shown in Figure 1.[9] Under technical efficiency rural households are producing at point A where the marginal product of labor equals the ratio of wage rate and crop price in absolute value terms. Subsequently, they use markets to trade to their optimal consumption point (B in Figure 1), at which the ratio of market prices equals the MRS between leisure and aggregate marketed good (again in absolute terms). In order to meet their demand from crop product, household members work off-farm. Off-farm income provide cash to the household so they can consume the desired amount of crop product at point B. The amount of labor required to produce the profit maximizing output is $\bar{T}-x_0^f$. Accordingly the amount of hours employed off-farm is $x_0^f-x_0^o$. If, however, farm production is technically inefficient household members realize only $y\times g(s,t)$ of maximum potential crop production. If production and consumption decisions are not separable, household members are rational, and leisure a normal good the! y make the necessary adjustments to equate again the marginal product of their labor with the ratio of wage rate and effective crop price ($p^y\theta^p$) at point C. They reduce on-farm employment by $x_1^f-x_0^f$ obtaining returns equal to $\tilde{\pi}^f\left(p^y g\left(s,t\right),w^v,x^f,t\right)$ as shown in the graph. On the consumption side the MRS between leisure and crop produce is now equated with the new price ratio in a lower indifference curve at point D. Off-farm employment is increased by $(x_0^o-x_1^o)+(x_1^f-x_0^f)$ in order to compensate for the profit losses suffered from farm activities. In this instance technical inefficiency is measured by the

[9] In our graphical exposition rural households are assumed to be net sellers of labor. The analysis can be carried out when households are net buyers of labor input.

distance between actual and maximal potential frontier, whereas profit efficiency by the restricted profits under technical inefficiency over those under technical efficiency indicated by point A.

Provided that $\tilde{\pi}^f$ and π^f are known to the household members, using duality results, and relation (6), the solution of the utility maximization problem in (8) under technical inefficiency defines the indirect utility function in a standard manner:

$$\begin{aligned} V\left(p^c, \pi^f, w^o, \tilde{M}, \theta^\pi\right) &= \max_{\ell^f,\ell^o,c}\left\{u\left(\ell^f,\ell^o,c\right) : \tilde{M} = p^c c + \tilde{\pi}^f \ell^f + w^o \ell^o\right\} \\ &= \max_{\ell^f,\ell^o,c}\left\{u\left(\ell^f,\ell^o,c\right) : \tilde{M} = p^c c + \theta^\pi \pi^f \ell^f + w^o \ell^o\right\} \\ &= \tilde{v}\left(p^c, \theta^\pi \pi^f, w^o, \tilde{M}\right) \end{aligned} \tag{10}$$

The indirect utility defined above is continuous, quasi-convex in p^c, π^f, w^o and $\tilde{M}$, non-increasing in p^c, π^f and w^o, non-decreasing in $\tilde{M}$ and homogeneous of degree zero in p^c, π^f, w^o and $\tilde{M}$.

Using *Roy's* identity, we can derive the *Marshallian* demand functions for ℓ^f, ℓ^o and c, *i.e.*,

$$\begin{aligned} \ell^f\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right) &= -\frac{V_f\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right)}{V_M\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right)} \\ &= -\frac{\tilde{v}_{\tilde{f}}\left(p^c, \theta^\pi \pi^f, w^o, \tilde{M}\right)}{\tilde{v}_M\left(p^c, \theta^\pi \pi^f, w^o, \tilde{M}\right)}\theta^\pi \end{aligned} \tag{11}$$

$$\begin{aligned} \ell^o\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right) &= -\frac{V_o\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right)}{V_M\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right)} \\ &= -\frac{\tilde{v}_o\left(p^c, \theta^\pi \pi^f, w^o, \tilde{M}\right)}{\tilde{v}_M\left(p^c, \theta^\pi \pi^f, w^o, \tilde{M}\right)} \end{aligned} \tag{12}$$

$$\begin{aligned} c\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right) &= -\frac{V_c\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right)}{V_M\left(p^c, \tilde{\pi}^f, w^o, \tilde{M}, \theta^\pi\right)} \\ &= -\frac{\tilde{v}_c\left(p^c, \theta^\pi \pi^f, w^o, \tilde{M}\right)}{\tilde{v}_M\left(p^c, \theta^\pi \pi^f, w^o, \tilde{M}\right)} \end{aligned} \tag{13}$$

where subscripts denote the partial derivative of $V(\cdot)$ or $\tilde{v}(\cdot)$ in f, o, c and $\tilde{M}$ whereas $\tilde{v}_{\tilde{f}}(\cdot)$ the partial derivative of $\tilde{v}(\cdot)$ with respect to its second argument $\theta^\pi w^f$. Thus, $\bar{T} - \frac{\tilde{v}_{\tilde{f}}(\cdot)}{\tilde{v}_M(\cdot)}$ is the optimal chosen maximal potential on-farm labor supply associated with existing price of marketed good, market wage rate and quasi-rents realized from farming activities. Optimal supply is the product of that maximal potential labor supply and profit efficiency.

Utility changes for household members associated with the presence of technical inefficiency in crop production is the difference between maximal possible utility obtained from on- and off-farm employment opportunities and utility realized in the presence of technical inefficiency and the associated reduction in quasi-rents obtained from farming. From (10) we can calculate overall household efficiency as:

$$\Theta^h = v\left(p^c, w^f, w^o, M\right) - \tilde{v}\left(p^c, \theta^\pi w^f, w^o, \tilde{M}\right) \tag{14}$$

where $v(\cdot)$ is obtained from (8) when $\theta^p = 1$. In percentage terms of actually attained utility, it can be expressed as:

$$\theta^h = \frac{\tilde{v}\left(p^c, \theta^\pi w^f, w^o, \tilde{M}\right)}{v\left(p^c, w^f, w^o, M\right)} \tag{15}$$

which is the overall household efficiency in the presence of technical inefficiency in farm production. This is less (greater) than one if the income effect from reduced farm profits is greater (lower) from the corresponding substitution effect between the two types of leisure.

Data and Econometric Setup

Farm Data

The data used for the estimation of the agricultural household model are from the *Farm Business Survey* for UK and refer to an unbalanced panel dataset of 296 farms for the cropping period 2001-2004. The database provides information on all the price and quantity variables required to estimate econometrically the model. All farms in the sample are based exclusively on household members for their operation producing all crop outputs considered (*i.e.*, no hired labor). Further, all sample participants exhibit non-zero hours of work off-farm implying the absence of corner solutions either for outputs produced or for off-farm working hours.

Three outputs were considered (*i.e.*, wheat, barley and oilseeds) for which arable CAP regime ensures different levels of area payments and three variable inputs (*i.e.*, seeds, chemical fertilizers and land). The survey also includes data on the number of hours of off-farm work for household members, the number of hours worked on-farm, the off-farm wage rate and, the household's non-labor income. Total short-run profits have been computed as the sum of total gross sales and total CAP production aid minus total variable costs divided by hours worked on-farm. Non-labor household income was measured as the asset income generated from off-farm investments, assuming a 6 percent rate of return. Household off-farm wage rate was calculated as the weighted average of individual wage rates (farmer and spouse) with hours of work off-farm used as weights. For the price of aggregate marketed good, we use a regional-specific consumer price index published by the *UK Department of Environment, Food and Rural Affairs* (formerly MAFF).

Given the policy regime under the recent CAP reform and following Sckokai and Moro (2006), three policy variables were included into the model: the total decoupled area payments, the set-aside payments and the set-aside percentage. Finally, we have used manager's education level and age as separate explanatory variables in both the production (*i.e.*, factors affecting managerial ability) and consumption equations (*i.e.*, taste shifters). Summary statistics of the variables are presented in Table 1. All prices are real prices, *i.e.*, nominal prices, deflated by the producer price index also published by the *UK Department of Environment, Food and Rural Affairs* (DEFRA, 2002).

Empirical Model

We choose the following transcedental logarithmic (translog) specification for the restricted profit function:

$$\begin{aligned}\ln \tilde{\pi}_{it}^{f} &= \beta_0 + \beta^y \ln \tilde{p}_{it}^{y} + \sum_j \beta_j^v \ln w_{jit}^v + \beta^t t + \sum_j \beta_j^{yv} \ln \tilde{p}_{it}^{y} \ln w_{jit}^v \\ &+ 0.5 \left[\beta^{yy} \left(\ln \tilde{p}_{it}^{y}\right)^2 + \sum_j \sum_k \beta_{jk}^{vv} \ln w_{jit}^v \ln w_{kit}^v + \beta^{tt} t^2 \right] \end{aligned} \quad (16)$$

where $i = 1, ..., N$ and $t = 1, ..., T$ stands for households and time, respectively, $\tilde{p}_{it}^{y} = p_{it}^{y} g(s_{it}, t)$. Symmetry and reciprocity property implies the following restrictions in (16): $\beta_{jk}^{vv} = \beta_{kj}^{vv}$. In addition, linear homogeneity in output and variable input prices require the following parameter restrictions: $\beta^y + \sum_j \beta_j^v = 1$, $\beta^{yy} + \sum_j \beta_j^{yv} = 0$, $\beta_j^{yv} + \sum_k \beta_{jk}^{vv} = 0 \; \forall j$, and $\beta^{ty} + \sum_j \beta_j^{tv} = 0$. Homegeneity restrictions are imposed by normalizing the restricted *translog* profit function in (16) using one output or variable input price as *numeraire.*

Our empirical specification for $g(s_{it}, t)$ follows the contribution of Aigner *et al.*, (1977) in the stochastic frontier literature defined as:

$$g_{it}\left(s_{it}, t\right) = \exp\left(-\delta_0 - \sum_h \delta_h s_{hit} - \delta_t t - \delta_{tt} t^2\right) \quad (17)$$

Using (16), (17) and *Hotelling's* lemma the associated output supply and variable input demands in quasi-rent share form are given by

$$S_{it}^{y} = \beta^y + \beta^{yy}\left(\ln p_{it}^{y} + \ln g_{it}\right) + \textstyle\sum_j \beta_j^{yv} \ln w_{jit}^v + \beta^{ty} t \quad (18)$$

$$-S_{jit}^{v} = \beta_j^v + \textstyle\sum_k \beta_{jk}^{vv} \ln w_{kit}^v + \beta_j^{yv}\left(\ln p_{it}^{y} + \ln g_{it}\right) + \beta_j^{tv} t \quad (19)$$

where S^y_{it} denotes the revenue share in quasi-rent and S^v_{jit} denotes the share of the j^{th} variable factor in quasi-rent.

We also approximate the indirect utility function in (10) by a *translog* specification which expresses the logarithm of the indirect utility by a function quadratic in the logarithms of the ratios of prices to the value of total expenditures and time (Jorgenson and Lau, 1975):

$$\begin{aligned}\ln \tilde{v}_{it} &= \alpha_0 + \alpha_\pi \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} + \alpha_w \ln \frac{w^o_{it}}{M_{it}} + \alpha_c \ln \frac{p^c_{it}}{M_{it}} + \alpha_{\pi w} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} \ln \frac{w^o_{it}}{M_{it}} + \alpha_{\pi c} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} \ln \frac{p^c_{it}}{M_{it}} \\ &+ \alpha_{wc} \ln \frac{w^o_{it}}{M_{it}} \ln \frac{p^c_{it}}{M_{it}} + 0.5 \left[\alpha_{\pi\pi} \left(\ln \frac{\tilde{\pi}^f_{it}}{M_{it}} \right)^2 + \alpha_{ww} \left(\ln \frac{w^o_{it}}{M_{it}} \right)^2 + \alpha_{cc} \left(\ln \frac{p^c_{it}}{M_{it}} \right)^2 \right] \quad (20)\end{aligned}$$

where again $i = 1, ..., N$ and $t = 1, ..., T$ stands for households and time, respectively, and $\tilde{\pi}^f (p^y \theta^p, w^v, s, t) = \theta^\pi \pi^f (p^y, w^v, t)$. Using (20) the expenditure shares for both kinds of leisure and aggregate marketed good can be derived using the logarithmic form of *Roy's* identity, *i.e.*,

$$\frac{\partial \ln \tilde{v}_{it}}{\partial \ln (p_{kit}/M_{it})} = S^k_{it} \sum_j \frac{\partial \ln \tilde{v}_{it}}{\partial \ln (p_{jit}/M_{it})}$$

with $k, j = \tilde{\pi}^f, w^o, p^c$ as:

$$S^q_{\pi it} = \frac{\alpha_\pi + \alpha_{\pi\pi} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} + 0.5 \left[\alpha_{\pi w} \ln \frac{w^o_{it}}{M_{it}} + \alpha_{\pi c} \ln \frac{p^c_{it}}{M_{it}} \right]}{\alpha_m + \alpha_{m\pi} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} + \alpha_{mw} \ln \frac{w^o_{it}}{M_{it}} + \alpha_{mc} \ln \frac{p^c_{it}}{M_{it}}} \quad (21)$$

$$S^q_{wit} = \frac{\alpha_w + \alpha_{ww} \ln \frac{w^o_{it}}{M_{it}} + 0.5 \left[\alpha_{\pi w} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} + \alpha_{wc} \ln \frac{p^c_{it}}{M_{it}} \right]}{\alpha_m + \alpha_{m\pi} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} + \alpha_{mw} \ln \frac{w^o_{it}}{M_{it}} + \alpha_{mc} \ln \frac{p^c_{it}}{M_{it}}} \quad (22)$$

$$S^q_{cit} = \frac{\alpha_c + \alpha_{cc} \ln \frac{p^c_{it}}{M_{it}} + 0.5 \left[\alpha_{\pi c} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} + \alpha_{wc} \ln \frac{w^o_{it}}{M_{it}} \right]}{\alpha_m + \alpha_{m\pi} \ln \frac{\tilde{\pi}^f_{it}}{M_{it}} + \alpha_{mw} \ln \frac{w^o_{it}}{M_{it}} + \alpha_{mc} \ln \frac{p^c_{it}}{M_{it}}} \quad (23)$$

where $\alpha_m = \alpha_\pi + \alpha_w + \alpha_c$, $\alpha_{m\pi} = \alpha_{\pi\pi} + \alpha_{\pi w} + \alpha_{\pi c}$, $\alpha_{mw} = \alpha_{\pi w} + \alpha_{ww} + \alpha_{wc}$ and $\alpha_{mc} = \alpha_{\pi c} + \alpha_{wc} + \alpha_{cc}$. Assuming utility maximization for rural households, the equality restrictions imply that the M-parameters appearing in each equation must be the same. The budget constraint implies that expenditure share equations sum to unity, so that given the parameters of any two equations the parameters of the third equation can be obtained from the definitions of the M-parameters above. Finally, since the equations for the expenditure shares are homogeneous of degree zero we normalize the parameters of the indirect translog utility function so that $\alpha_M = -1$.

Econometric Estimation

The joint estimation of system of equations (21)-(23) and (18)-(19) by Seemingly Unrelated Regressions (SUR) is not a trivial task. In particular the joint estimation of the parameters of the technical inefficiency equation given by, $\theta^p = \exp\left(-\delta_0 - \delta_{Age} \times Age_{it} - \delta_{Edu} \times Edu_{it} - \delta_t \times t - \delta_{tt} \times t^2\right)$ and of the remaining parameters of the system, can lead to several identification problems, making the convergence of non linear algorithms a difficult task. To overcome this problem we suggest a two step concentrated nonlinear least squares method grid search method. In the first step we estimate the parameters $\boldsymbol{\theta^p} = [\delta_0,\ \delta_{Age},\ \delta_{Edu},\ \delta_t,\ \delta_{tt}]^\intercal$, from (18)-(19), using a multi search procedure while in the next step conditional on the first stage estimates we estimate the remaining parameters.

Note that since the estimates of $\boldsymbol{\theta^p}$ are obtained through a multi search procedure it will not be possible to get an estimate of the variance-covariance matrix. In order to overcome this problem we suggest the following bootstrap statistical method,

Step 1: Estimate the system of equations (21)-(23) and (18)-(19) by SUR under the null hypotheses, $H_0 : \boldsymbol{\theta^p} = 0$ and compute the residuals denoted by $\hat{v}_{it}^{(j)}$, where $j = 1, 2$ for (21)-(23) and (18)-(19) respectively

Step 2: Generate K boostrap samples of size T by taking random draws from the distribution of $\hat{v}_{it}^{(j)}$ and compute the boostrap residuals defined as $\hat{v}_{it}^{(jk)} = \hat{v}_{it}^{(j)}\left(1 - d_{it}\right), k = 1, \cdots, K$ where d_{it} is a zero mean, unit variance random variable generated by the Rademacher distribution given below,

$$d_{it} = \begin{cases} 1 & \text{with probability } \frac{1}{2} \\ -1 & \text{with probability } \frac{1}{2} \end{cases} \tag{24}$$

Step 3: Based on the values $\boldsymbol{\theta^p}$ under the null and the bootstrap residuals $\hat{v}_{it}^{(jk)}$, compute K bootstrap samples of the dependent variable, denoted by $\xi_{it}^{(jk)}$.

Step 4: Given $\xi_{it}^{(jk)}$, estimate jointly (21)-(23) and (18)-(19) for each boostrap sample k.

Step5: Save the K point estimates of $\boldsymbol{\theta^p}$ and compute their standard deviation.

Empirical Results

Profit Function Estimation

The parameter estimates of the the household model, namely the profit and indirect utility functions estimates, are presented on Table 2. Most coefficients of the profit function are significant at the 1% level except for the price interaction term between seeds and intermediate inputs which is significant at the 5% level, while the price terms for seeds and intermediate inputs as well as the quadratic price term for intermediate inputs are not significant. The estimates of the inefficiency model on the bottom part of the table show that technical efficiency decreases with farmer's age while it increases with the farmer's level of education, a result reported in other studies (Seyoum et. al., 1998; Battese and Coelli, 1995). If the quadratic term of the time variable is taken into account, the estimates show that farmers tend to be less efficient in time, an unexpected result that could be due to factors other than age and education having an influence on inefficiency.

Table 3 presents the estimated output supply and variable input demand elasticities and shows that most are significant at the 1% level and a few at the 10% level, while some cross-price elasticities are not significant even at the 10% level. The demand for seeds appears to be unresponsive to changes in the prices of both fertilizers and intermediate inputs while the demand for the latter two is unresponsive to changes in the price of seeds. Cereals supply is inelastic with respect to changes in its own price (elasticity of 0.559) as well as with respect to changes in the input prices, with the price of fertilizers producing the greatest negative response in cereal supply with an elasticity of -0.212. The small responses in the supply of output might be due to limitations in altering cropping areas. The uncompensated own-price elasticities are negative and inelastic for all inputs, with intermediate inputs being the most inelastic with a value of -0.480. Inputs response to output price changes is inelastic for seeds and inermediate inputs but elastic for fertilizers. Turning now to the compensated demand elasticities it trascends that all three inputs are net substitutes to each other. In general the own-price compensated input demand elasticities are much smaller than the uncompensated ones implying that an important part of input adjustment to changes in prices is due to the expansion or scale effect.

Indirect Utility Function Estimation

Turning now to the estimates of the indirect utility function on Table 2, it trascends that all coefficients are significant at the 1% level. Table 4 presents the demand elasticities for on-farm leisure, off-farm leisure and marketed good which are all significant at the 1% level. Moreover the table shows that in the case of own-price elasticities for the two types of leisure most of the adjustment to a price change comes from the substitution effect as the compensated elasticities are quite close to the uncompensated ones, while in the case of the marketed good the income effect is relatively higher. The compensated elasticities show that on-fam leisure, off-farm leisure and the marketed good are net substitutes to each other. In addition on-farm leisure and off-farm leisure are much more responsive to changes in their own prices than the marketed good. All goods are normal goods but inelastic as evidenced by the estimates on the last column of Table 4, especially in the case of on-farm leisure where the income elasticity is equal to 0.460.

The elasticities of the two types of leisure and aggregate marketed good with respect to variable input and crop prices are reported on Table 5. An increase in the output price p_y will lead to an increase in the demand of the marketed good and in the demand of off-farm leisure, while the effect on on-farm leisure is negative. However the elasticity of off-farm leisure with respect to output price is quite small. Recall that an increase in the output price has a positive effect on profits and therefore both on income and on the shadow price of on-farm labor, thus leading to an increase in the demand of both the marketed good and off-farm leisure while the effect of increased income and higher shadow price have opposite signs on on-farm leisure. Increases in the variable input prices will lead to a decrease in profits and thus have both a positive (lower shadow price of labor) and negative (lower income) effect on on-farm leisure while they will affect negatively the demand of the other two goods, although the effects are quite small. Overall, the demand for the three types of goods is much more responsive to changes in the output price than to changes in the prices of inputs and in the case of on-farm labor the demand elasticity with respect to output price is almost one in absolute terms.

Efficiency Measurement

The descriptive statistics of the estimates of technical, profit and household efficiency by year are reported on Table 6 . The yearly mean technical efficiency remains quite stable over the first two years at around 81% but then falls in the following two years to a level of 75%, which means that the average output loss due to technical inefficiency goes from 19% to 25%. It is worth noting that the dispersion of values is only 0.002. Likewise, the average profit efficiency falls after 2002 from a level of 75% to 61% which means that technical inefficiency produces an average profit loss of around 39%. The mean household efficiency falls every successive year but the most striking feature is the increase in its variability as the stndard deviation goes from 0.061 in 2001 to 0.102 in 2004. While it is the case that all farmers face very similar levels of technical efficiency, their household efficiency levels span over a big range of values with 25% of the farm households having household efficiency scores below 76% in 2004 and one quarter having household efficiency scores above 91.7%.

The first plot in Figure 2 shows that the distribution of technical efficiency scores is very concentrated around the mean, remains almost unchanged between 2001 and 2002 but then shifts to the left so that the support of the distribution in 2004 has no values in common with the supports of the previous years. The distribution of profit efficiency scores depicted in the second plot of Figure 2 is more spread but displays a shift to lower values in time as well. In addition the spread of values is slightly larger for the last year 2004. In the case of household efficiency the third plot in Figure 2 shows that the dispersion of values increases considerably in time and is much higher than in the case of the other efficiencies. The figures show that although all farmers exhibit similar values of technical efficiency, they display quite different values of household efficiency. These facts are further illustrated with more detail in the beeswarm boxplots in Figure 3 which show a much smaller clustering of values in the case of household efficiency.

In order to further analyze the behavior of efficiencies, the farm size in UAA, the autonomous income and the off-farm wage were each divided in four regions of values according to their quartiles and for each one of the four subsets of data the mean efficiencies have been computed. The mean efficiency estimates are given by Table 7 for farm size, Table 8 for autonomous income and Table 9 for off-farm wage. The mean efficiency estimates of both technical efficiency and profit efficiency are quite close over all four ranges of data for all three variables while for household efficiency it is the case that its mean increases as the quartile region increases for the three considered variables and the increase is quite large in the case of off-farm wage. One way to interpret these results is as follows, under the presence of technical inefficiency both the income and shadow price of on-farm labor will suffer a reduction and therefore give rise to an increase in off-farm labor, those farms with higher off-farm wages will be able to cope better with the loss of income caused by the presence of inefficiency. On the other hand, bigger farms can adapt better to technical inefficiency due to their better proximity to the labor market. In a recursive model technical inefficiency would affect consumption decisions only through its effect on reduced profits and thus income. The fact that in our model the shadow price of on-farm labor depends both on production and consumption decisions means that the model is not recursive and thus technical inefficiency will affect consumption decisions via two channels, the income of the farmer and the shadow price of labor.

Conclusions

While it has been recognized in the literature that farm households' decisions as producers affect their decsions about consumption and labor supply and vice-versa, previous studies on technical efficiency for farming units have not fully exploited the link between production and consumption in their analyses.

The present study proposes a household model where the aforementioned interdependence between production, consumption and labor supply decisions is taken into account while it includes the possibility of farm households to be technically inefficient in their productive activities. In addition, a measure of household inefficiency induced by technical inefficiency is proposed that can be readily estimated from the joint household model. Because the farm household is allowed to display different preferences for on-farm and off-farm labor, technical inefficiency will have both an income and substitution effect in the consumption decisions that will affect the hosehold's maximum achievable utility differently. Since technical efficiency will lead to both a decrease in income and a reduction in the shadow price of on-farm labor it is not clear at the outset what the final effect on household efficiency scores will be.

The empirical results show that technical efficiency scores are rather similar for the households in our sample while household efficiency scores show great variability over different households. Those farms that can secure higher off-farm wages, a higher autonomous income and that have larger sizes experience substantially higher household efficiency scores while their technical efficiency scores are similar to other farms. Of the aforementioned three factors, differences in off-farm wages received by the household produce the greatest differentials in household efficiency scores with low off-farm wage receiving farmers suffering substantial losses in their housåhold efficiency scores.

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Appendix A: Elasticity Calculation

Profit Function

- Uncompensated Variable-Input Demand Elasticities

$$\text{Own-Price:} \quad \varepsilon^v_{jj} = S^v_j - 1 + \frac{\beta^{vv}_{jj}}{S^v_j}$$

$$\text{Cross-Price:} \quad \varepsilon^v_{jk} = S^v_k + \frac{\beta^{vv}_{jk}}{S^v_j}$$

$$\text{Crop Price:} \quad \varepsilon^v_{jp} = S^y + \frac{\sum_k \beta^{vv}_{jk}}{S^v_j}$$

where $j, k = S, F, I$ are the three variable inputs used (*i.e.*, seeds, fertilizers and intermediate inputs) and p is the crop price.

- Crop Supply Elasticities

$$\text{Crop-Price:} \quad \varepsilon^y_p = -\sum_j S^v_j + \frac{\sum_j \sum_k \beta^{vv}_{jk}}{S^y}$$

$$\text{Variable-Input Price:} \quad \varepsilon^y_j = S^v_j + \frac{\sum_k \beta^{vv}_{jk}}{S^y}$$

- The matrix of Compensated Variable-Input Demand Elasticities is obtained from:

$$\begin{bmatrix} \epsilon^v_{SS} & \epsilon^v_{SF} & \epsilon^v_{SI} \\ \epsilon^v_{FS} & \epsilon^v_{FF} & \epsilon^v_{FI} \\ \epsilon^v_{IS} & \epsilon^v_{IF} & \epsilon^v_{II} \end{bmatrix} = \begin{bmatrix} \varepsilon^v_{SS} & \varepsilon^v_{SF} & \varepsilon^v_{SI} \\ \varepsilon^v_{FS} & \varepsilon^v_{FF} & \varepsilon^v_{FI} \\ \varepsilon^v_{IS} & \varepsilon^v_{IF} & \varepsilon^v_{II} \end{bmatrix} - \begin{bmatrix} \varepsilon^v_{Sp} \\ \varepsilon^v_{Fp} \\ \varepsilon^v_{Ip} \end{bmatrix} \begin{bmatrix} \varepsilon^y_p \end{bmatrix}^{-1} \begin{bmatrix} \varepsilon^y_S & \varepsilon^y_F & \varepsilon^y_I \end{bmatrix}$$

Indirect Utility Function

- Uncompensated Leisure and Aggregate Marketed Good Demand Elasticities

$$\text{Own-Price:} \quad \varepsilon^d_{jj} = \frac{\alpha_{jj}}{Z_j} - \frac{\alpha_{mj}}{Q} - 1$$

$$\text{Cross-Price:} \quad \varepsilon^d_{jk} = \frac{0.5\alpha_{jk}}{Z_j} - \frac{\alpha_{mk}}{Q}$$

$$\text{Income:} \quad \varepsilon^d_{jm} = -\sum_k \varepsilon^d_{jk}$$

where $j, k = \ell^f, \ell^o, c$ are the two leisures and aggregate marketed good and Z_j and Q are the numerator and the denominator, respectively, of the corresponding budget shares.

- Uncompensated Leisure and Aggregate Marketed Good Demand Elasticities w.r.t. to variable-input and crop prices

$$\text{Crop Price:} \quad e^d_{jp} = \left(\varepsilon^d_{\pi j} + \varepsilon^d_{\pi m} \frac{\bar{T}\tilde{\pi}^f}{M} \right) S^y$$

$$\text{Variable-Input Price:} \quad e^d_{jq} = \left(\varepsilon^d_{\pi j} + \varepsilon^d_{\pi m} \frac{\bar{T}\tilde{\pi}^f}{M} \right) S^v_q$$

with q being the variable-inputs used (*i.e.*, seeds, fertilizers and intermediate inputs).

- Compensated Leisure and Aggregate Marketed Good Demand Elasticities

$$\text{Own-Price:} \quad \epsilon^d_{jj} = \varepsilon^d_{jj} + S^h_j \varepsilon^d_{jm}$$

$$\text{Cross-Price:} \quad \epsilon^d_{jk} = \varepsilon^d_{jk} + S^h_k \varepsilon^d_{jm}$$

Tables and Figures

Figure 1: Agricultural Household Model Under Technical Inefficiency in Farm Production

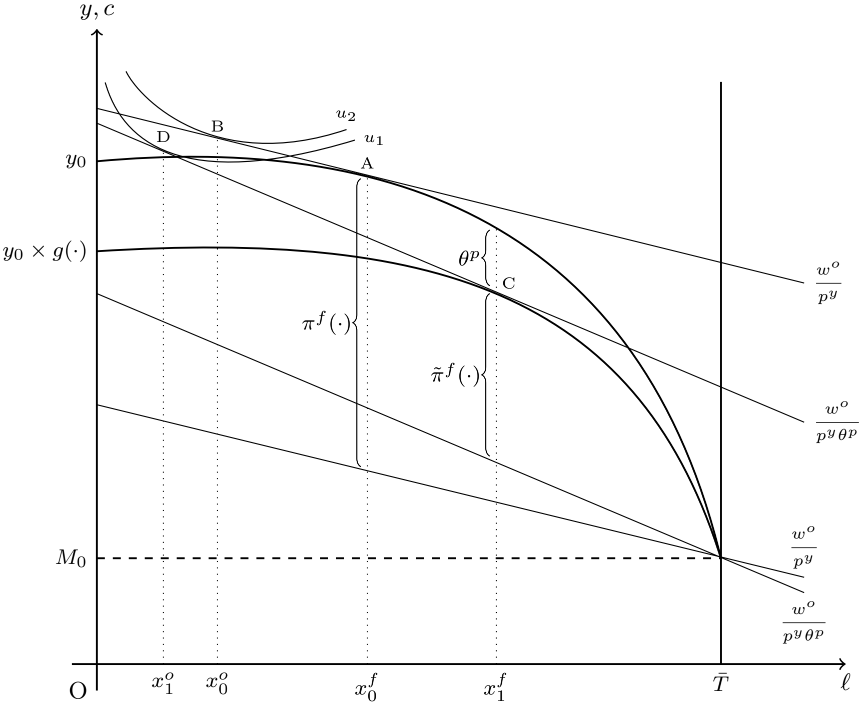

Table 1: Descriptive Statistics of Variables

Variable Description and Name	Mean	St. Dev.	Minimum	Maximum
Wheat Production (tonnes)	497.1	657.852	3.0	6000
Barley Production (tonnes)	173.3	248.618	3.0	2959.6
Oilseed Rape Production (tonnes)	54.477	100.527	3.00	794
Wheat Price	72.60	9.889	45	105.32
Barley Price	74.13	9.815	50	109.34
Oilseed Rape Price	154.5	21.40	111	221
Quantity Seeds	34362	51360.57	1009	512120
Quantity Fertilizers	3066	3021.059	137.6	20848.5
Quantity Intermediate Inputs	175.4	191.162	7.22	1586.74
Price Seeds	0.240	0.046	0.112	0.354
Price Fertilizers	3.297	0.541	2.140	4.660
Price Intermediate Inputs	46.32	11.14	22.7	57.63
On-Farm labor (hours)	2926	2178.137	200	9857
Off-Farm labor (hours)	1279	757.922	50	5625
Profits	18.701	8.724	7.745	82.860
Off-Farm wage	9.56	4.801	2.767	26.786
Age	50.41	8.884	27	75
Education	3.22	1.531	1	9
Autonomous Income (thousands euros)	2.959	5.874	0.05	82.8
UAA (hectares)	175.4	191.162	7.22	1586.74
CPI deflator	7.237	0.653	6.3	7.98

Table 2: Parameter Estimates of the Translog Short-Run Profit and Indirect Utility Functions

Parameter	Estimate	StdError	Parameter	Estimate	StdError
Short-Run Profit Function			*Indirect Utility Function*		
β_0	2.156	(0.086)***	α_m	-1	
β^y	1.133	(0.071)***	α_π	-0.362	(0.002)***
β^{yy}	-0.249	(0.046)***	$\alpha_{\pi\pi}$	-0.236	(0.003)***
β^y_S	0.098	(0.024)***	$\alpha_{\pi w}$	-0.143	(0.004)***
β^y_F	0.052	(0.019)***	$\alpha_{\pi c}$	-0.266	(0.003)***
β^y_I	0.099	(0.014)***	α_w	-0.215	(0.003)***
β^v_S	-0.007	(0.038)	α_{ww}	-0.088	(0.003)***
β^v_F	-0.118	(0.029***	α_{wc}	-0.153	(0.002)***
β^v_I	-0.007	(0.022)	α_c	-0.422	(0.006)***
β^{vv}_{SS}	-0.054	(0.019)***	α_{cc}	-0.329	(0.010)***
β^{vv}_{FF}	-0.058	(0.018)***	$\alpha_{m\pi}$	-0.645	(0.005)***
β^{vv}_{II}	-0.011	(0.021)	α_{mw}	-0.385	(0.007)***
β^{vv}_{SF}	-0.024	(0.014)***	α_{mc}	-0.749	(0.010)***
β^{vv}_{SI}	-0.019	(0.008)**			
β^{vv}_{FI}	0.031	(0.008)***			
β^t	0.070	(0.063)			
β^{tt}	0.078	(0.025)***			
Inefficiency Model					
δ_0	1.627	(0.055)***			
δ_{Age}	0.060	(0.033)*			
δ_{Edu}	-0.001	(0.0001)***			
δ_t	-0.149	(0.010)***			
δ_{tt}	0.049	(0.108)			
Log-Likelihood	1379.09			667.346	
Number of obs.	495			495	

Where y stands for crop output, S for seeds, F for fertilizers, I for intermediate inputs, π for restricted farm profits, w for off-farm wage rate, c for aggregate marketed goods and m for household income. The corresponding standard errors are obtained using block resampling techniques (Politis and Romano 1994). Significance levels: ***1%, ** 5%, * 10%.

Table 3: Variable-Input Demand and Crop Supply Elasticities

	Price of:			
	Cereals	Seeds	Fertilizers	Intermediate Inputs
Output Supply				
Cereals	0.559	-0.174	-0.212	-0.172
	(0.001)	(0.001)	(0.001)	(0.001)
Uncompensated Demand Elasticities				
Seeds	0.944	-0.840	-0.056	-0.048
	(0.001)	(0.001)	(0.518)	(0.502)
Fertilizers	1.413	-0.181	-0.918	-0.314
	(0.001)	(0.834)	(0.001)	(0.061)
Intermediate Inputs	0.886	-0.051	-0.355	-0.480
	(0.001)	(0.451)	(0.052)	(0.001)
Compensated Demand Elasticities				
Seeds	-	-0.545	0.303	0.242
		(0.001)	(0.091)	(0.125)
Fertilizers	-	0.347	-0.428	0.081
		(0.001)	(0.001)	(0.001)
Intermediate Inputs	-	0.215	0.006	-0.221
		(0.007)	(0.101)	(0.001)

Elasticities are computed at the mean values of all exogenous variables and distortion parameters. In parentheses are the corresponding p-values.

Table 4: On- and Off-Farm Leisure and Aggregate Marketed Good Demand Elasticities Conditional on Farm Profits

	Short-run Profits	Off-farm Wage Rate	Price of Marketed Good	Autonomous Income
Uncompensated Demand Elasticities				
On-Farm Leisure	-1.095	0.764	-0.129	0.460
	(0.001)	(0.001)	(0.001)	(0.001)
Off-Farm Leisure	0.270	-1.039	-0.146	0.916
	(0.001)	(0.001)	(0.001)	(0.001)
Marketed Good	-0.114	-0.078	-0.652	0.844
	(0.001)	(0.001)	(0.001)	(0.001)
Compensated Demand Elasticities				
On-Farm Leisure	-0.924	0.865	0.060	-
	(0.003)	(0.003)	(0.001)	
Off-Farm Leisure	0.609	-0.837	0.230	-
	(0.001)	(0.001)	(0.001)	
Marketed Good	0.198	0.108	-0.306	-
	(0.001)	(0.001)	(0.001)	

Elasticities are computed at the mean values of all exogenous variables. The unconditional (supply and demand) elasticities with respect to the price of aggregate marketed good coincide with the conditional ones. In parentheses are the corresponding p-values.

Table 5: On- and Off-Farm Labor Supply and Aggregate Marketed Good Demand Elasticities with Respect to Variable Inputs and Crop Prices

	Price of:			
	Cereals	Seeds	Fertilizers	Intermediate Inputs
On-Farm Leisure	-0.924	0.083	0.102	0.082
	(0.001)	(0.001)	(0.001)	(0.001)
Off-Farm Leisure	0.090	- 0.010	-0.012	-0.011
	(0.001)	(0.001)	(0.001)	(0.001)
Marketed Good	0.287	-0.010	-0.013	-0.011
	(0.001)	(0.001)	(0.001)	(0.001)

Elasticities are computed at the mean values of all exogenous variables. In parentheses are the corresponding p-values.

Table 6: Descriptive Statistics of Farm Technical (TE), Profit (PE) and Household (HE) Efficiency Estimates: 2001-04

	TE	PE	HE	TE	PE	HE
		2001			2002	
Minimum	0.807	0.675	0.766	0.807	0.667	0.740
First Quartile	0.810	0.725	0.850	0.811	0.738	0.826
Median	0.812	0.745	0.888	0.812	0.761	0.865
Mean	0.812	0.742	0.891	0.812	0.752	0.875
Third Quartile	0.813	0.762	0.935	0.814	0.770	0.924
Maximum	0.817	0.798	1.0	0.815	0.791	1.0
Stand. Dev.	0.002	0.024	0.061	0.002	0.027	0.066
		2003			2004	
Minimum	0.787	0.609	0.685	0.741	0.491	0.560
First Quartile	0.791	0.690	0.818	0.746	0.600	0.760
Median	0.793	0.707	0.869	0.748	0.624	0.817
Mean	0.793	0.702	0.874	0.748	0.616	0.834
Third Quartile	0.794	0.720	0.940	0.750	0.638	0.917
Maximum	0.797	0.745	1.010	0.755	0.674	1.0
Stand. Dev.	0.002	0.025	0.079	0.003	0.030	0.102
Average Period Estimates:						
Technical Eff.: 0.787		Profit Eff.: 0.695		Household Eff.: 0.867		

Table 7: Mean Efficiency Estimates by Quartiles of UAA: 2001-04

	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
		2001				2002		
Technical Efficiency	0.812	0.811	0.812	0.812	0.811	0.812	0.812	0.812
Profit Efficiency	0.737	0.745	0.744	0.743	0.746	0.768	0.753	0.741
Household Efficiency	0.870	0.883	0.892	0.919	0.868	0.872	0.868	0.891
		2003				2004		
Technical Efficiency	0.792	0.792	0.793	0.793	0.748	0.748	0.749	0.749
Profit Efficiency	0.701	0.707	0.704	0.697	0.619	0.621	0.615	0.610
Household Efficiency	0.852	0.864	0.874	0.907	0.792	0.839	0.840	0.866

Figure 2: Density Plots of Technical/Profit/Household Efficiency

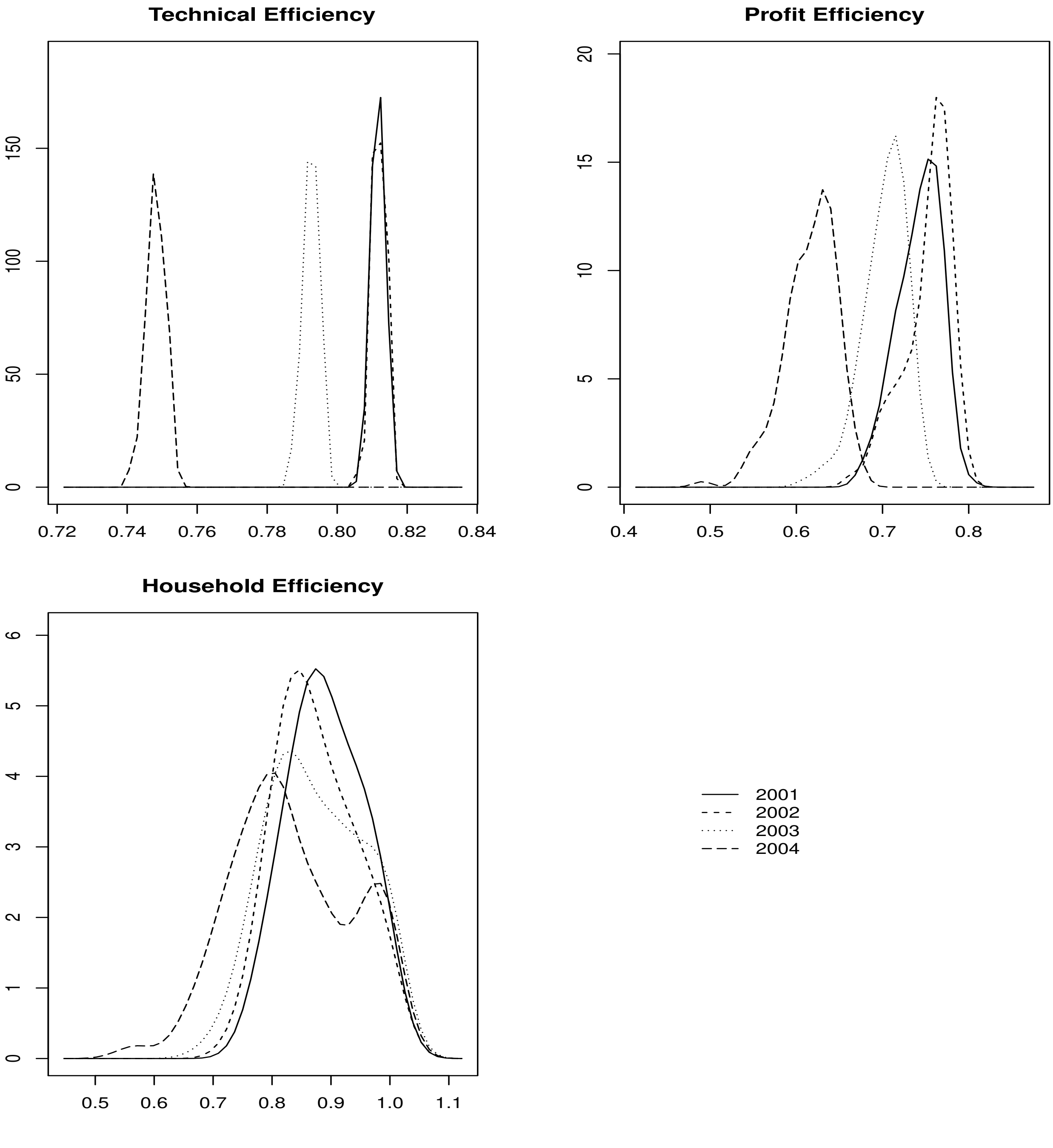

Figure 3: Beeswarm Boxplots of Efficiencies

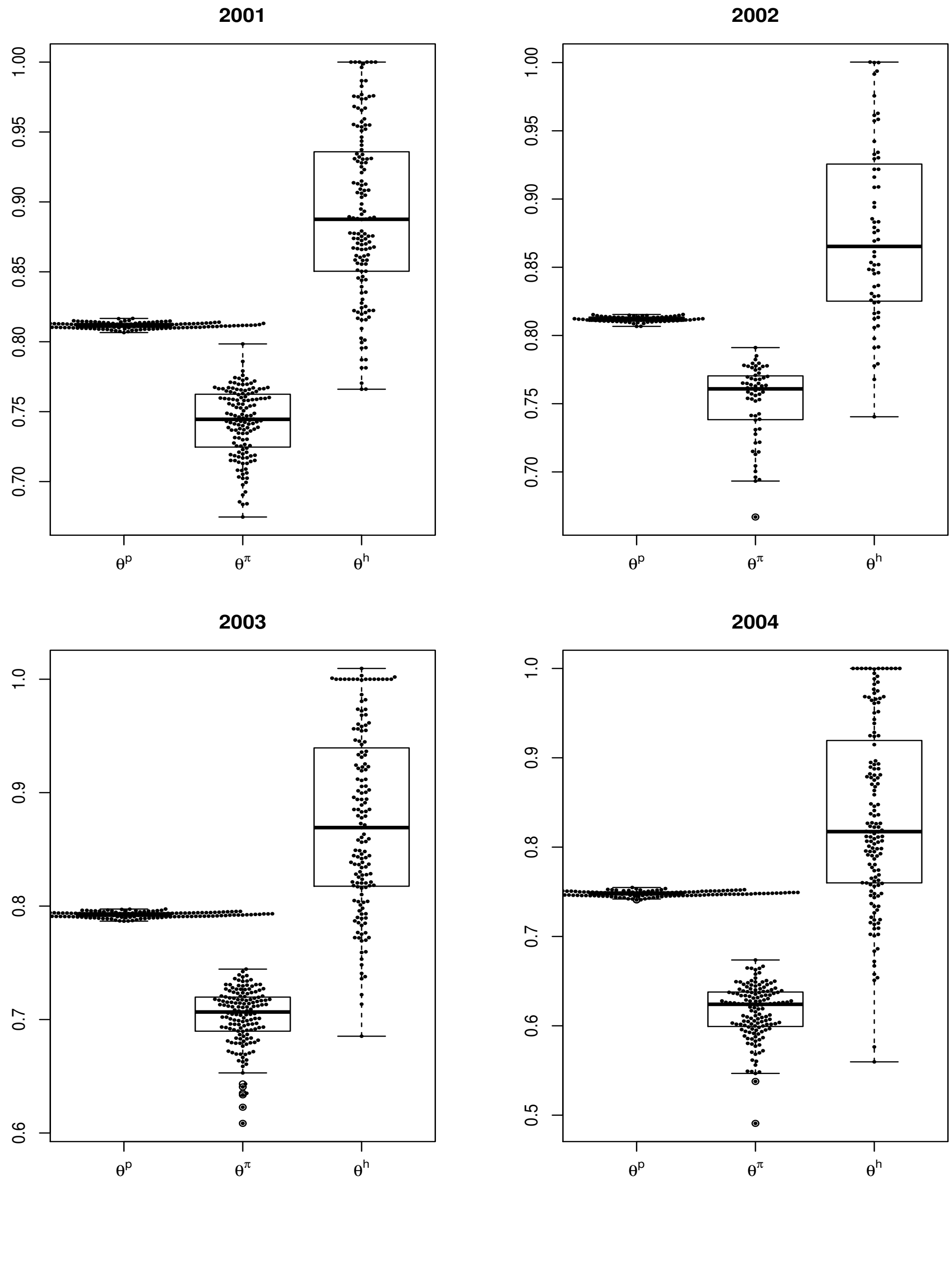

Table 8: Mean Efficiency by Quartiles of Autonomous Income: 2001-04

	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2001				2002			
Technical Efficiency	0.812	0.812	0.812	0.811	0.812	0.813	0.813	0.812
Profit Efficiency	0.734	0.746	0.747	0.749	0.745	0.759	0.752	0.756
Household Efficiency	0.878	0.890	0.894	0.897	0.877	0.852	0.866	0.886
	2003				2004			
Technical Efficiency	0.793	0.793	0.793	0.793	0.748	0.749	0.749	0.747
Profit Efficiency	0.705	0.694	0.708	0.709	0.612	0.616	0.622	0.612
Household Efficiency	0.850	0.867	0.878	0.904	0.819	0.838	0.827	0.842

Table 9: Mean Efficiency by Quartiles of Off-farm Wage Rate: 2001-04

	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2001				2002			
Technical Efficiency	0.812	0.811	0.812	0.812	0.812	0.812	0.812	0.812
Profit Efficiency	0.735	0.738	0.748	0.747	0.756	0.744	0.749	0.759
Household Efficiency	0.826	0.872	0.909	0.957	0.813	0.867	0.871	0.947
	2003				2004			
Technical Efficiency	0.792	0.792	0.793	0.793	0.748	0.748	0.748	0.749
Profit Efficiency	0.704	0.699	0.703	0.705	0.610	0.607	0.628	0.619
Household Efficiency	0.793	0.833	0.903	0.968	0.727	0.788	0.861	0.961